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Investigation of the thermal state of an asynchronous motor with an asymmetric magnetic circuit

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Abstract. Modern technology for the processing of spent fuel assemblies (SFA) and radioactive waste (RW) is utilized in radiation protection cells. Under the conditions of exposure to high radiation fields, there is an intense destruction of various assemblies of actuators made of organic materials, including insulation of motor windings, which leads to frequent equipment failures requiring repair or replacement. Within the limits of the existing need, a project is being developed, with the purpose of creation of a radiation-resistant asynchronous electric motor with ceramic insulation for operation in. The proposed technical solutions make possible to increase the service life of the engine operating under the influence of radiation fields in radiation protection chambers by 4-5 times. Operation under an extreme condition requires an assessment of the engine itself. Considering a non-standard cooling system is of crucial importance for such projects.

1. Introduction

The departments “Electric Machines” and “Rare Metals and Nanomaterials” of UrFU develop asynchronous motors capable of operating in technological installations for various purposes under the extreme conditions of exposure to radiation fields and high temperatures or in chemically aggressive environment.

One of the perspective directions is the development of an asynchronous motor with an asymmetric magnetic core (AMAMC).

2. AMAMCs design

AMAMC has the strongest differences in comparison with serial asynchronous motor. The new design was proposed to use a two-row concentrated three-phase winding with a shortened pitch equal to 1/3 pole division of the machine. Consisting of six monolithic coils, this winding has no intersecting frontal parts (Figure 1). The use of a winding with rigid coils required the stator core to be detachable. Therefore, in an experimental motor, the stator teeth are separated from the yoke. Fastening the teeth in the core is made with the help of dovetail tails.

To suppress the higher harmonic components of the field that inevitably arise when using a concentrated winding, a new method of compensating spurious electromagnetic moments has been applied [1]. The method is based on suppressing the EMF of the higher harmonics of the field in the rotor rods of an induction motor by dividing the stator core along two equal parts and the relative displacement of their phase zones by an angle corresponding to the pole division of the field harmonics from which rotor rods must be suppressed. The method is implemented by performing teeth with asymmetrical serrated tips and their displacement relative to the body of the tooth in



opposite directions. This method of suppressing the influence of higher harmonics is implemented in a rotor without groove beveling. To reduce the axial dispersion flow of the stator winding between the halves of the stator core, a non-magnetic insert with a thickness of 5-8 mm was used.

Since the ADAM design, a project of a radiation-resistant controlled engine of a vertical version of an extractors drive of technological installations with speed control for work in radiation-protective chambers for radioactive waste processing, with a capacity of 2.2 kW, with a synchronous speed of 1500 rpm, was developed. In contrast to the first prototype, several changes have been made to the ADAM design: the tine connector with the stator yoke and fastening using dovetails are eliminated. The connector is made on the border of the phase zones, and the stator core is made of 12 modules, according to the number of phase zones of the four-pole motor. The coils of the concentrated stator winding are wound directly on the teeth of both halves of the modules, separated by a non-magnetic gasket. Isolation of copper wire and coils is made using the radiation-resistant materials from the company CJSC Insulation Materials Plant Elinar with further impregnation with a compound of the brand Eplast-220, PJSC Elektroizolit.

The motor shell is made with a protection against external influences IP 68 stainless steel. Engines are made with water cooling. Therefore, the frame, in which the stator core with winding is pressed, has a shirt with inlet and outlet fittings for cooling water supply. The performance of the engines according to the method of protection from exposure to the external environment IP 68 assumes the hermetic design of the housing. In this regard, the rear bearing shields are made "deaf", i.e. the engine has one output end of the shaft at the front shield, in which a seal is applied using packing based on radiation-resistant graplex with spring preload. The seal is fixed by an outer bearing cap. The jacket of the liquid cooler and bearing shields of the engine have a natural heat exchange with the surrounding chemically aggressive medium, the temperature of which reaches $+80^{\circ}\text{C}$. In bearing units, bearings 40 of the brand "W 6307-27" by "SKF" are installed, filled with radiation-resistant grease with a maximum allowable working temperature of $+160^{\circ}\text{C}$. The bearing in the front shield is fixed by a bearing cap mounted on the inner surface of the shield. In the rear bearing shield, the bearing is fixed by an annular wave spring, which provides a temperature gap during thermal expansion of the rotor. A terminal box with a hermetically installed lid is welded to the rear bearing shield, to which a radiation-resistant cable in a flexible stainless steel sheath is attached to the threaded connection.

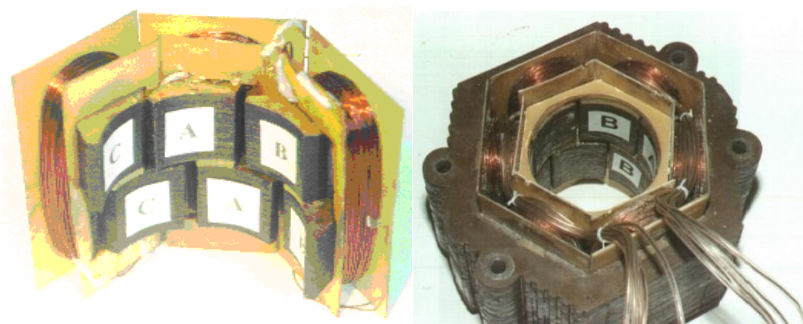


Figure 1. Stator teeth with phase coils and assembled stator of the first prototype of an asynchronous motor with an asymmetric magnetic circuit, developed by JSC UETM.

The use of the new design of ADAM with IP 68 protection and water cooling required the adjustment of the original electromagnetic calculation methods, including the methods for calculating the magnetic circuit, no-load current, and stator winding scattering parameters developed by the Electric Machines Department for asynchronous motors with an asymmetric magnetic circuit, and studying thermal engine condition. The method of thermal calculation is based on the method of equivalent thermal circuits (ETS). In the framework of this technique, a preliminary study of the water cooler was carried out to determine the heat transfer coefficient correlating with the flow rate of the cooling medium.

3. AMAMCs water cooler heat calculation

The calculation was carried out by FEM analysis in the Ansys package using the Geometry, Mesher and Ansys CFX modules.

Figure 2 shows the resulting geometry of an equivalent flat cooler with applied computational grids. Nozzles are placed in such a way as if on a cylindrical cooler they would be located opposite each other (180 degrees) and spaced in height. The internal diameter of the pipes is 10 mm. At the edges forming the “seam” of the cylinder, the boundary condition “periodicity” is set, which completely equalizes the equivalent flat cooler with the cylindrical cooling condition.

Then, in the Ansys Mesher module, the computational grids were constructed for two domains: a solid domain, the shell, and a liquid domain, water. The total number of items received - 2 578 801 pcs. The calculation grids are shown in Figure 2.

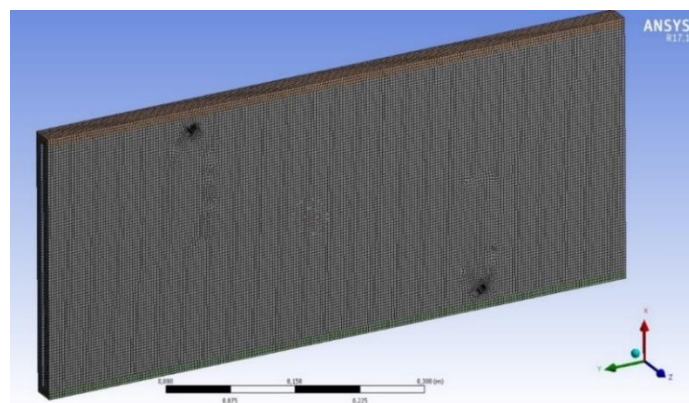


Figure 2. Calculation grids.

In the Ansys CFX module, 2 domains were created - the case and water, and the following boundary conditions and initial approximations were set for the formulation of the problem:

- The outer cooling surface has a boundary condition of the type “Heat transfer coefficient” with a value of 15 W/m²*C and an ambient temperature of 80°C;
- The inner surface of the body has a boundary condition of the type “Total power source” with a value corresponding to the total losses in the engine under study;
- At the water inlet, a boundary condition of the “Input” type is set up with a water velocity of 1.0 m/s (or a volumetric flow rate of 0.2 liters per second) and a temperature of 32°C;
- At the output of the coil, the boundary conditions of the “Discovery” type with a relative pressure of 0 Pa;

The field patterns in the two central sections of the cooler are shown in Figure 3. After the calculation, the following results were obtained:

- The temperature difference between water at a speed of 0.5 m/s at the entrance to the cooler and at the exit: 5.48°C;
- The loss of water pressure at a speed of 0.5 m/s in the pipe was 202 Pa;
- The heat transfer coefficient of the hull to water at a speed of 0.5 m/s was 1068 W/(m²*K)

Figure 4 shows the relationship between the pressure drop in the hydraulic path of the cooler, as well as the heat transfer coefficient of the walls of the cooler depending to the flow rate of the cooling medium. According to the graphs, it can be concluded that the heat transfer coefficient is very weakly influenced by the flow rate of the medium, so you can significantly save on creating the necessary pressure in the hydraulic path, you can seriously reduce its speed, while maintaining high efficiency of heat removal from the cooler surface.

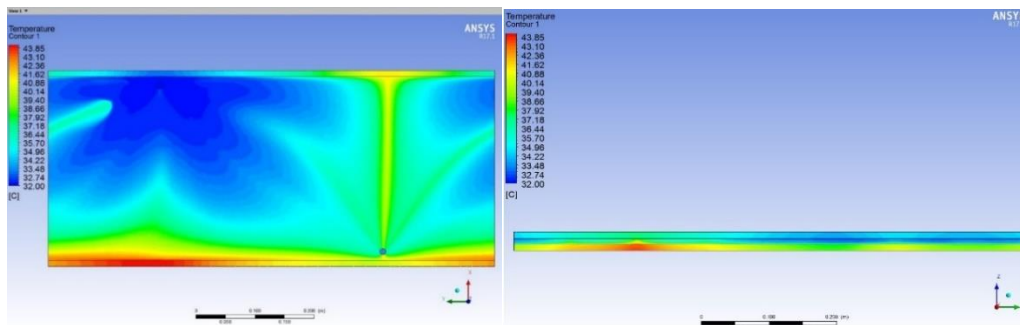


Figure 3. Temperature distribution of the cooler in two central sections

4. Heat state evaluation

Figure 5 shows the ETS ADAM under the assumption of symmetric cooling of the bearing shields and the frontal parts of the stator winding. The calculation of heat transfer coefficients and thermal resistances was carried out according to the methods developed for industrial electric machines [2]. The calculation of the thermal resistances of the slot part of the stator winding is made based on original techniques developed by the Department of "Electric Machines" for asynchronous motors with an asymmetric magnetic circuit. In assessing the thermal state of the engine, the dependence of the heat transfer coefficient on the cooling water flow rate, found as a result of the calculation of the liquid cooler by a numerical method (see Figure 4) based on the developed hull design, was used. The solution of the ETS system of equations is performed in a matrix form for 14 nodes in the MathCad environment.

A feature of the thermal regime when the engine is operating in a radiation protection chamber is the heating of the engine housing from the external environment, which has a higher temperature. In the thermal calculation, the heating of the case is taken into account approximately by increasing the water temperature at the inlet to the cooler by the heating temperature value, which corresponds to the total heat flow through the external surfaces, both of the cooler's jacket and the shields, from the external environment. The magnitude of the components of this flow was determined by the method of successive approximations according to the temperature difference between the respective surfaces and the environment.

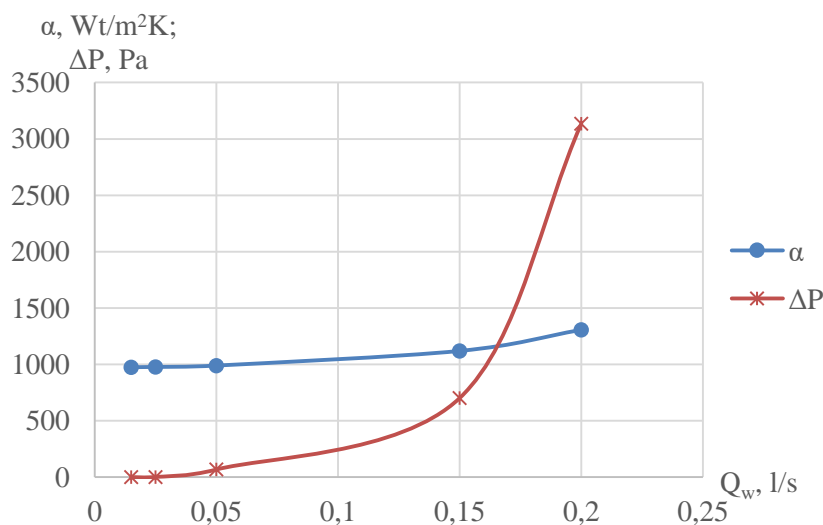


Figure 4. Relationship of heat transfer coefficient and pressure drop in the cooler between the flow of coolant in the channel.

Due to the increased consumption of steel on the engine and the saved dimensions in which it should fit, it was possible to create an efficient and compact cooling system. The magnitude of the average heat transfer coefficients at the surfaces of the cooler jacket and the shields was approximately determined by the dependence shown in Figure 4. The study in the simulation environment for finite elements showed that the temperature of the shirt and the body are about the same. At each step of the calculation, the parameters of the cooling water and the heat transfer coefficients depending on the flow rate were specified [6].

The temperature of the frontal part of the stator winding (node 11, Figure 2), determining the choice of insulation class of the machine, the average temperature of the bearing shields (node 2, Figure 2), determining the choice of lubrication of bearings, and the water temperature at the cooler outlet are presented on Figure 6.

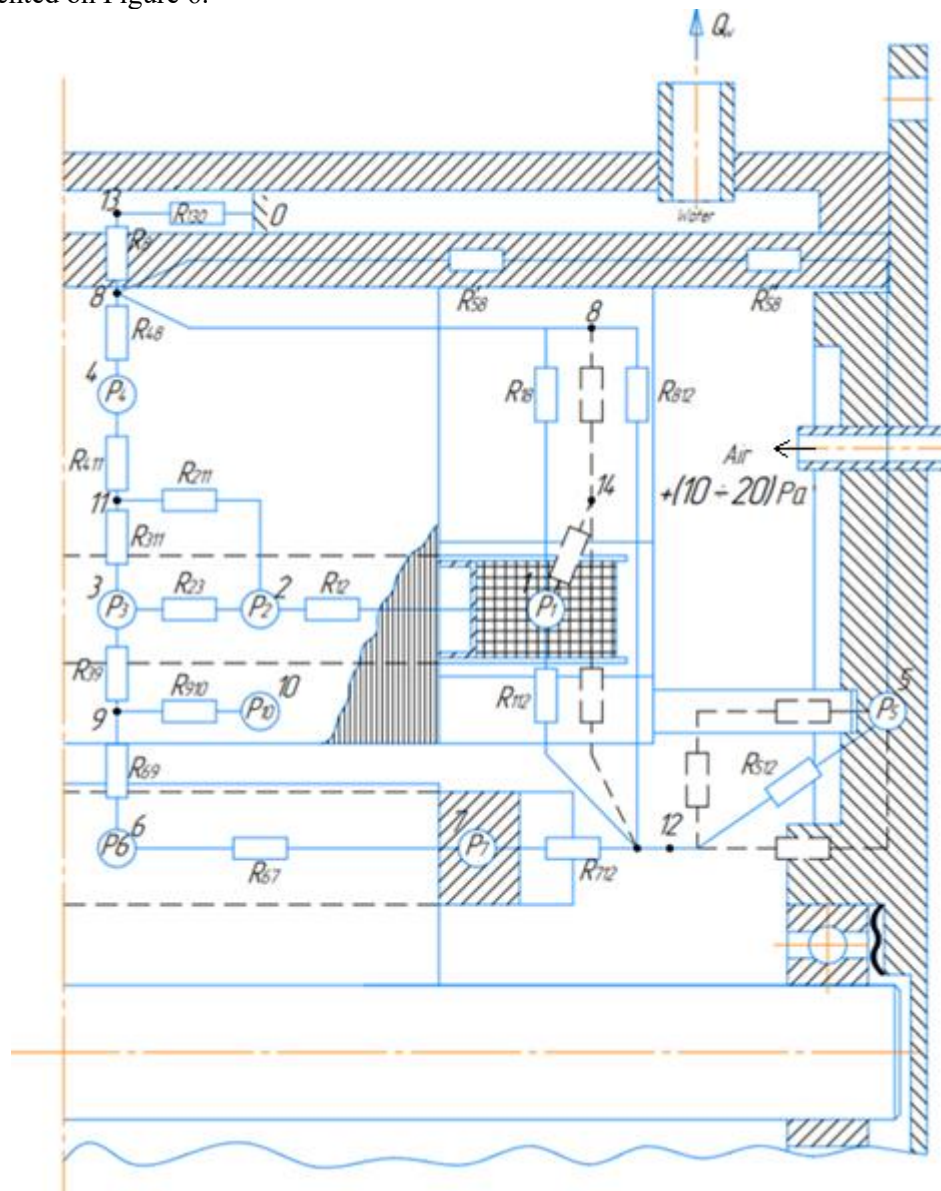


Figure 5. Equivalent thermal circuit of AMAMC.

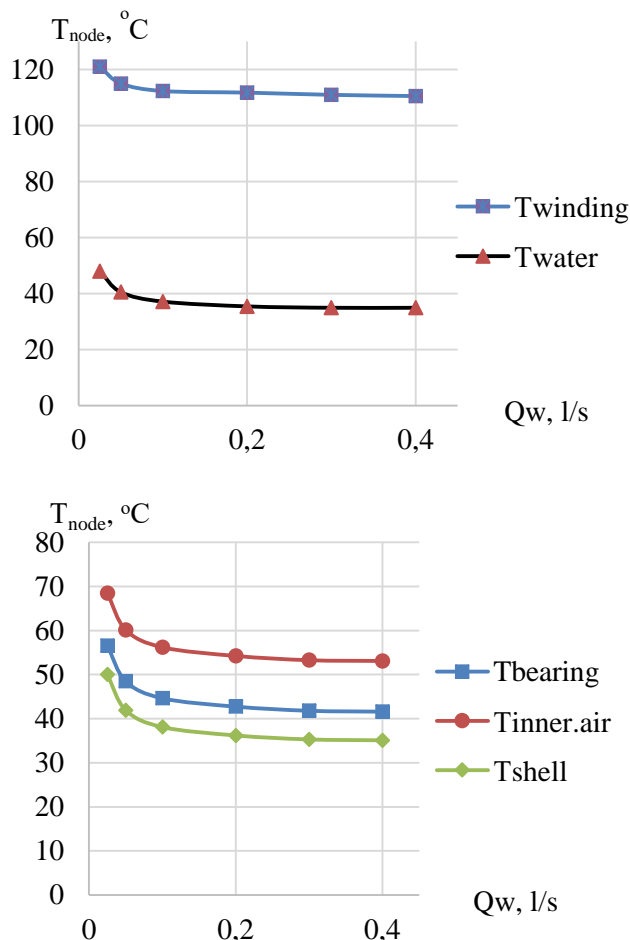


Figure 6. The results of the calculated relationship between the temperature and the flow of coolant in a motor, power of 2.2 kW, 1500 rev/min.

As the analysis showed for the designed cooling channel, it is advisable to take 0.05 l/s of the coolant flow rate. The increase in water consumption will not lead to a noticeable increase in engines efficiency and a corresponding increase in service life due to a decrease in electrical losses in the winding, and a reduction in consumption is not advisable, since it leads to an increase in overheating of the stator winding and a decrease in the specified machine characteristics.

Increased coolant flow rate reduces the temperature of the engine components. The motors used insulation of the stator winding, which permits heating temperatures up to 180°C, while in bearing units radiation-resistant grease with a permissible temperature of 160°C is used. This allows you to significantly save on creating the necessary pressure in the hydraulic path, that is, to reduce its speed, while maintaining high efficiency of heat removal from the surface of the cooler [7].

5. Conclusion

The heating level of the winding is no more than 122°C and does not exceed the allowable value of 180°C for radiation-resistant insulation, which meets the requirement of the technical specification and gives a temperature margin for possible overloads.

In the given conditions while creating the necessary pressure, the cooler successfully performs its function - the transferring of heat losses from the induction motor.

The use of double or triple impregnation of dry windings with intermediate dryers can guarantee that the life of asynchronous motor will be within 3 to 5 years.

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